



NASA GEOS model and DA System for AQ

K. Emma Knowland

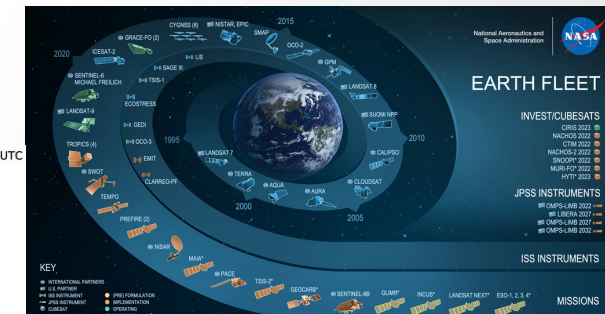
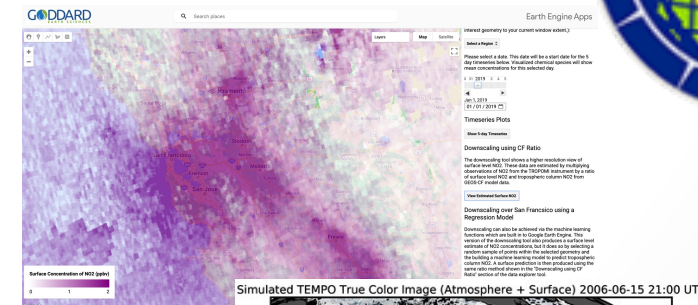
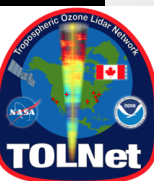
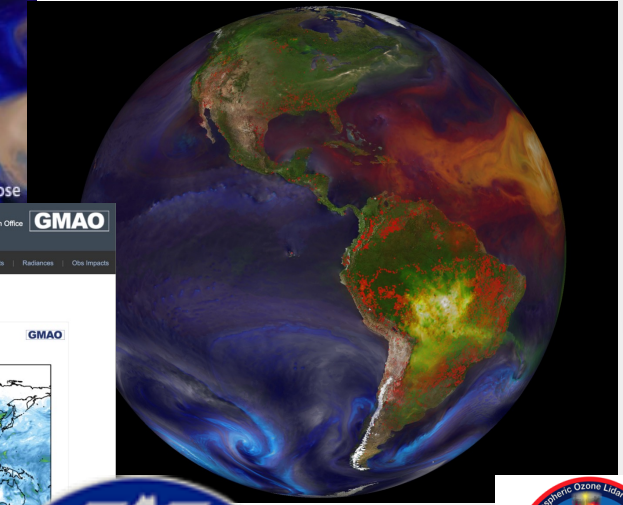
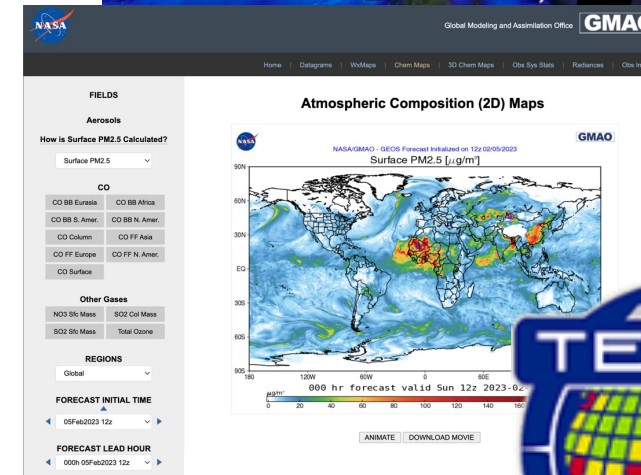
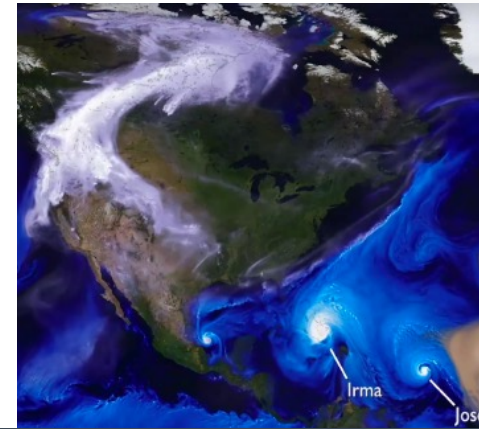
Morgan State University/GESTAR-II

NASA Global Modeling and Assimilation Office (GMAO)

**In collaboration with many scientists from GMAO and other labs at
NASA Goddard Space Flight Center**

OUTLINE

1. Overview of GEOS current capabilities
 - Numerical Weather Prediction
 - Aerosol and Constituent data assimilation systems
 - Composition Forecasting
2. How to access GEOS “big data” for research scientists and engaged community members
3. Applications
4. Future Direction



GMAO's core mission is to enhance the value of NASA's observations to understand, analyze and predict changes in the physics, chemistry and biology of the Earth system

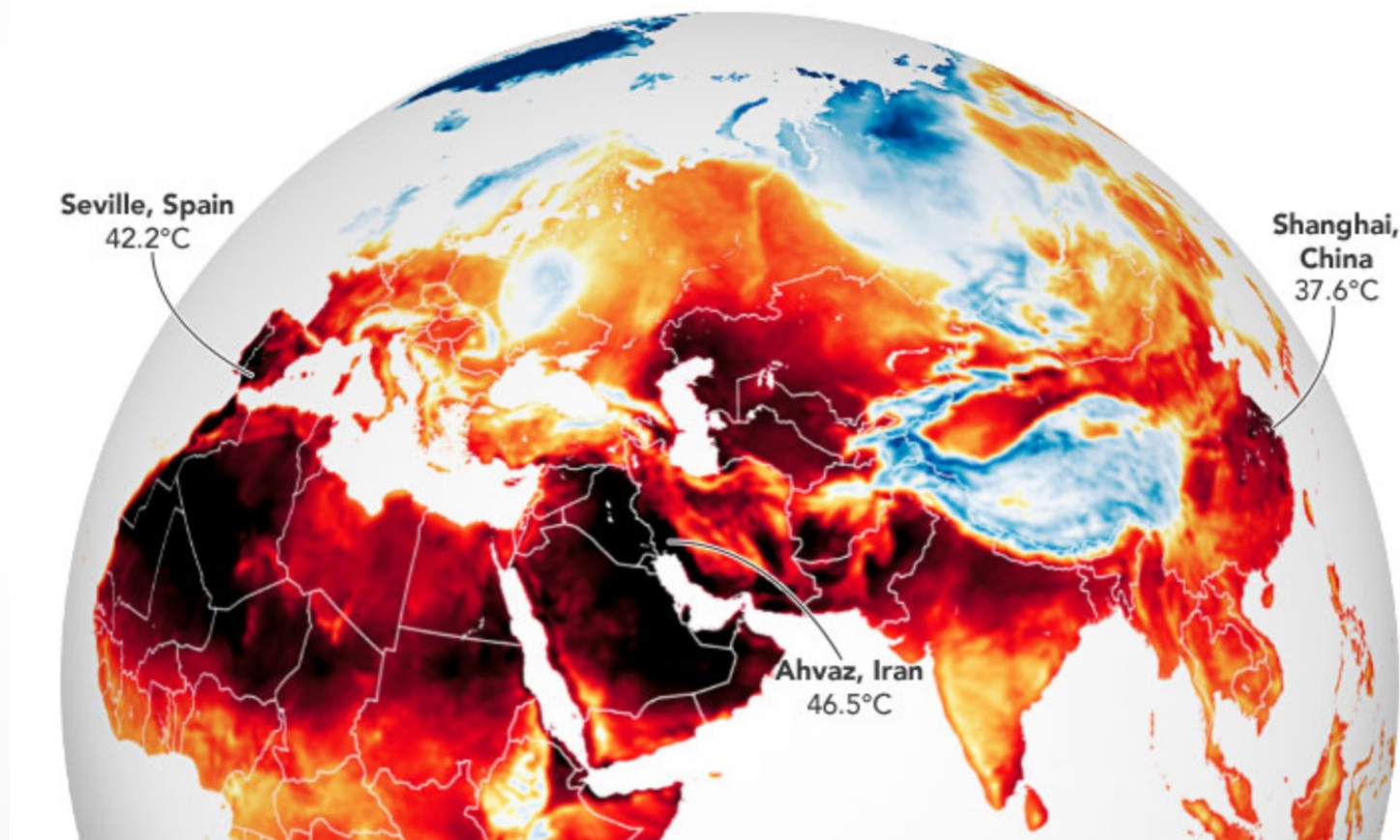
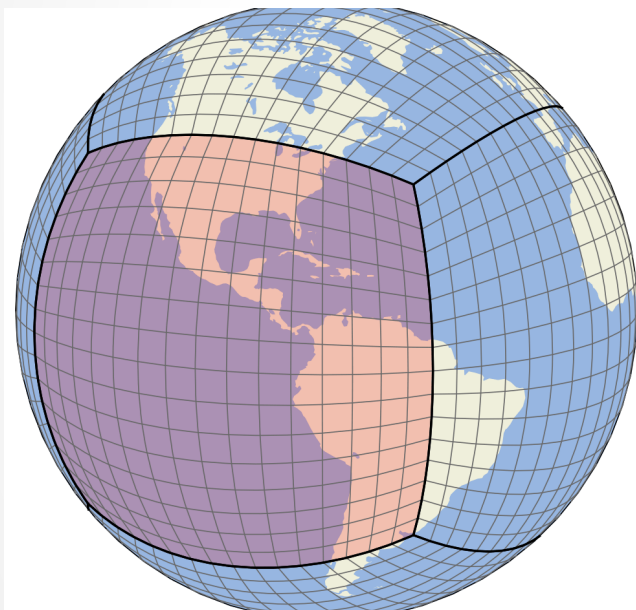


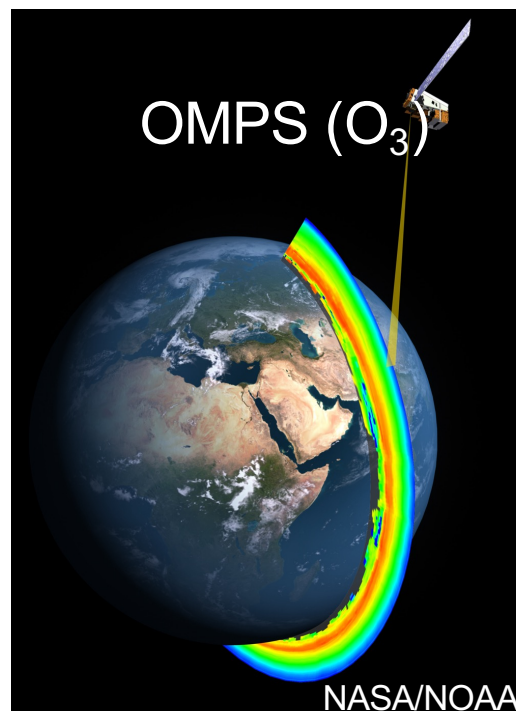
Image by Joshua Stevens,
NASA Earth Observatory
<https://earthobservatory.nasa.gov/images/150083/heatwaves-and-fires-scorch-europe-africa-and-asia>

NASA GMAO has a mature Earth System model

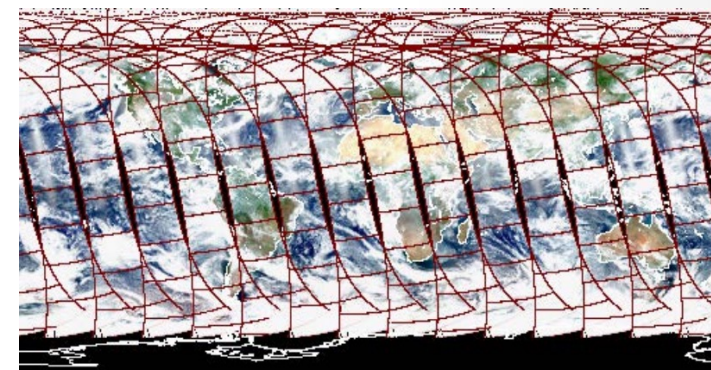
GEOS



Bindle et al., 2021 GMD

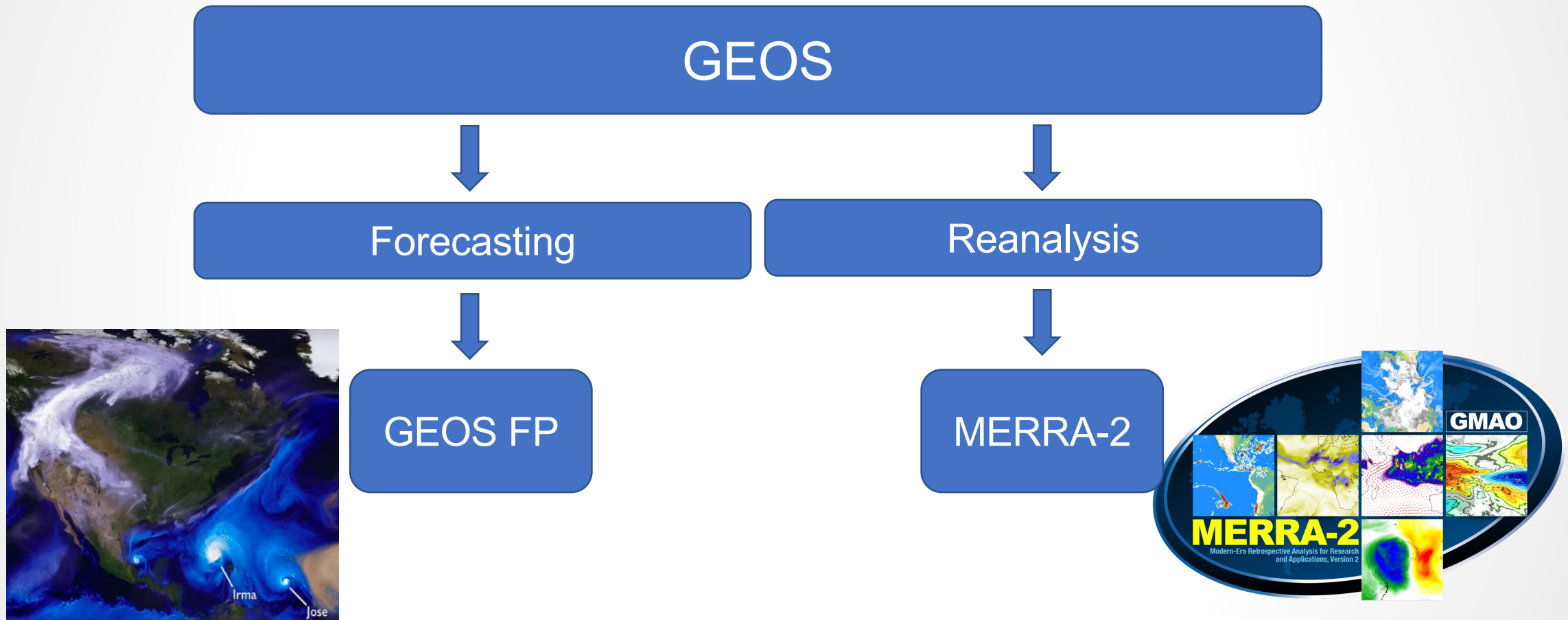


www.nasa.gov

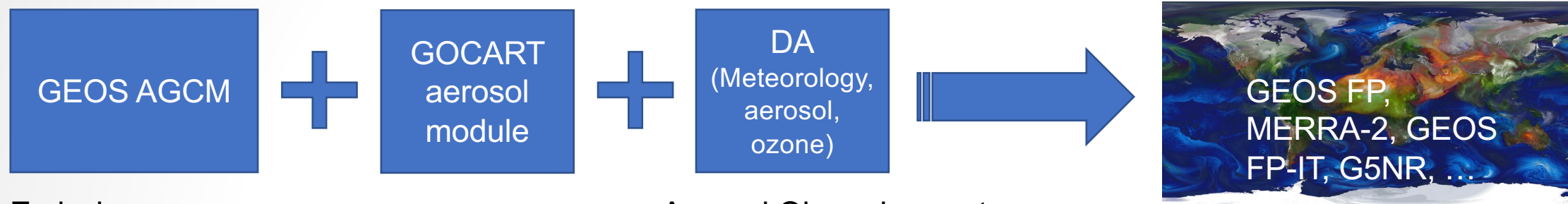


<https://modis.gsfc.nasa.gov/>

NASA GMAO global meteorology and chemistry products



GEOS aerosol data assimilation system



Emissions

Biomass Burning: HFED, QFED

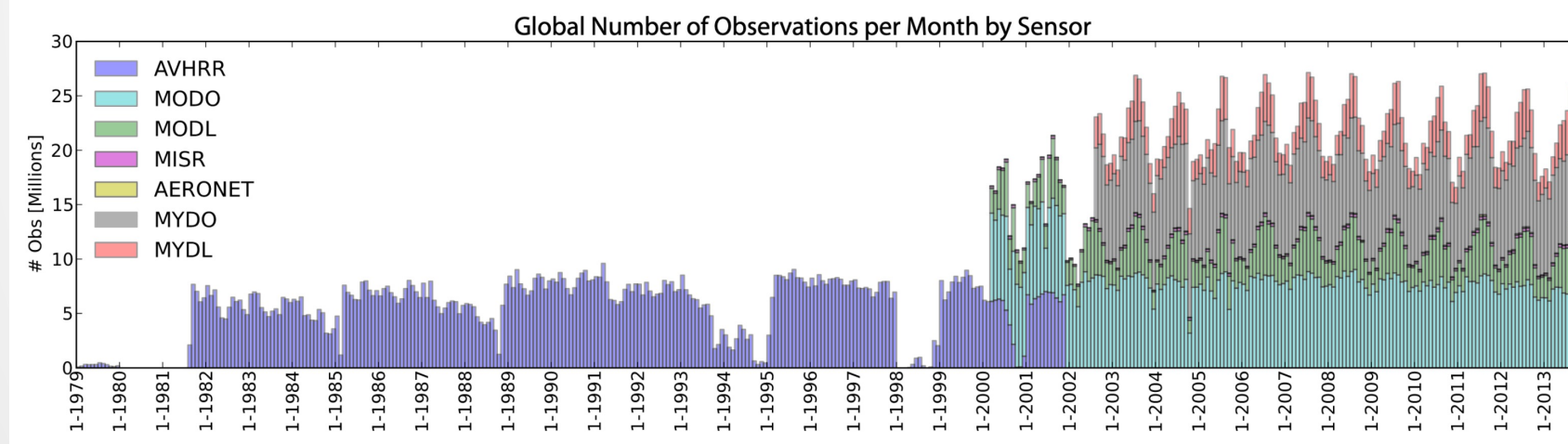
Anthropogenic: Edgar & AeroCom Phase II

Aerosol Observing system

Bias-corrected AOD (550 nm)

Particulate matter (PM):

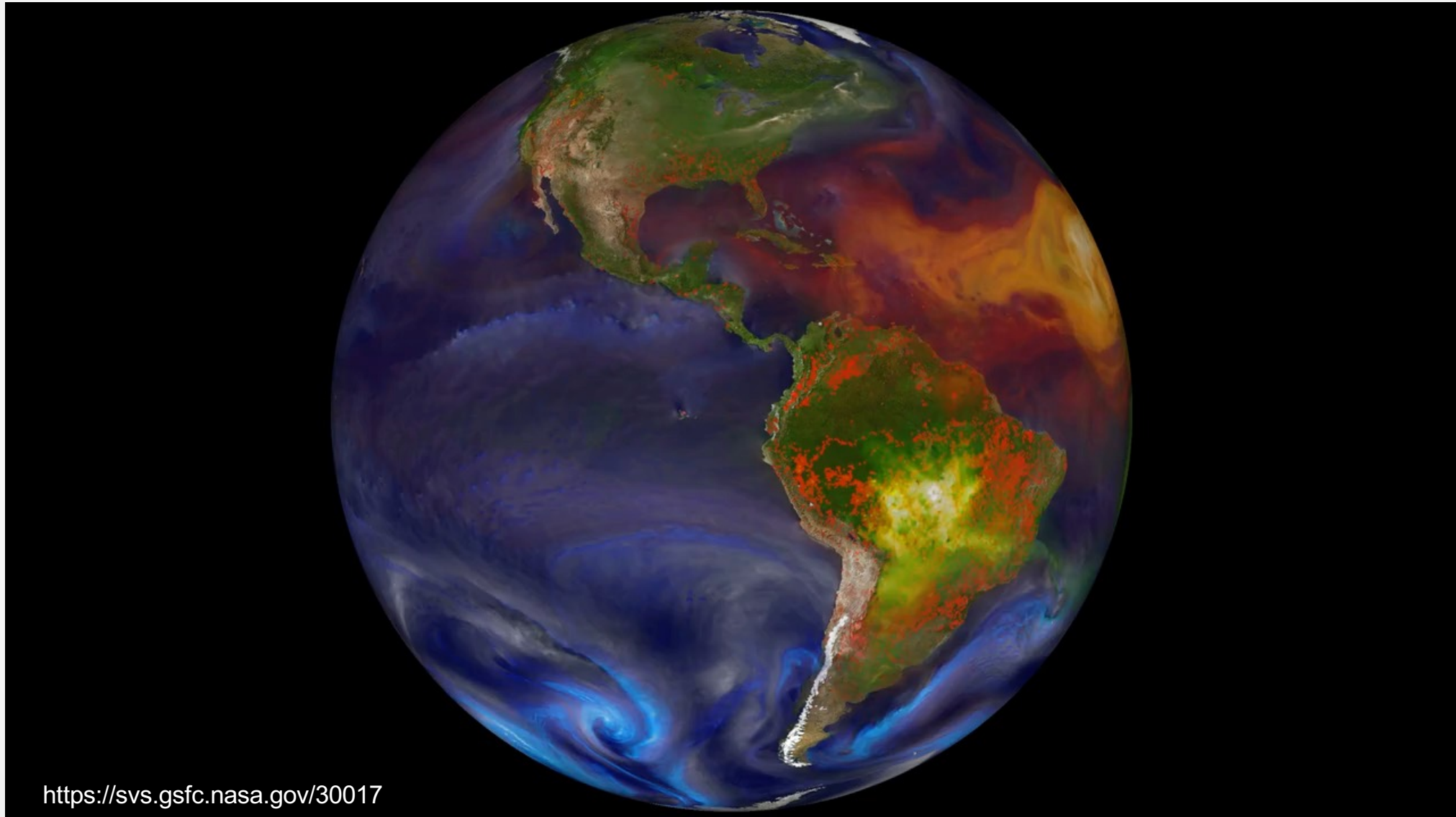
- Organic Carbon
- Black Carbon
- Sea salt
- Sulfate
- Dust
- Nitrate (GEOS FP)



Randles et al., 2016; NASA/TM-2016-104606/Vol. 45

Randles et al., 2017; DOI: 10.1175/JCLI-D-16-0609.1

GEOS NWP capabilities



GEOS FP and MERRA-2 PM_{2.5} available online

FLUID is a mobile-friendly
website

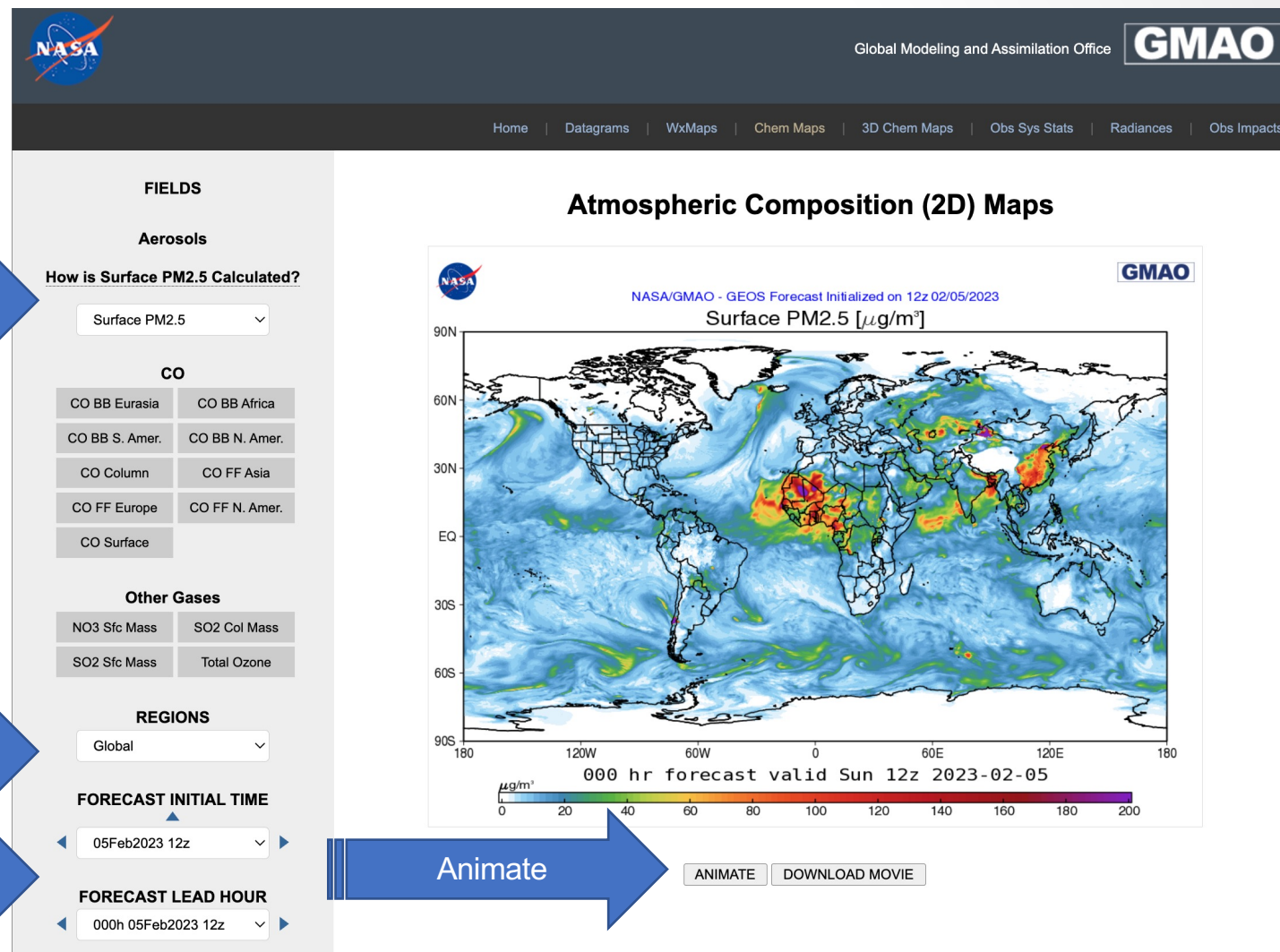
<https://fluid.nccs.nasa.gov/wxmaps/chem2d>

Select Surface PM_{2.5}

Select the region

Select Forecast

Animate

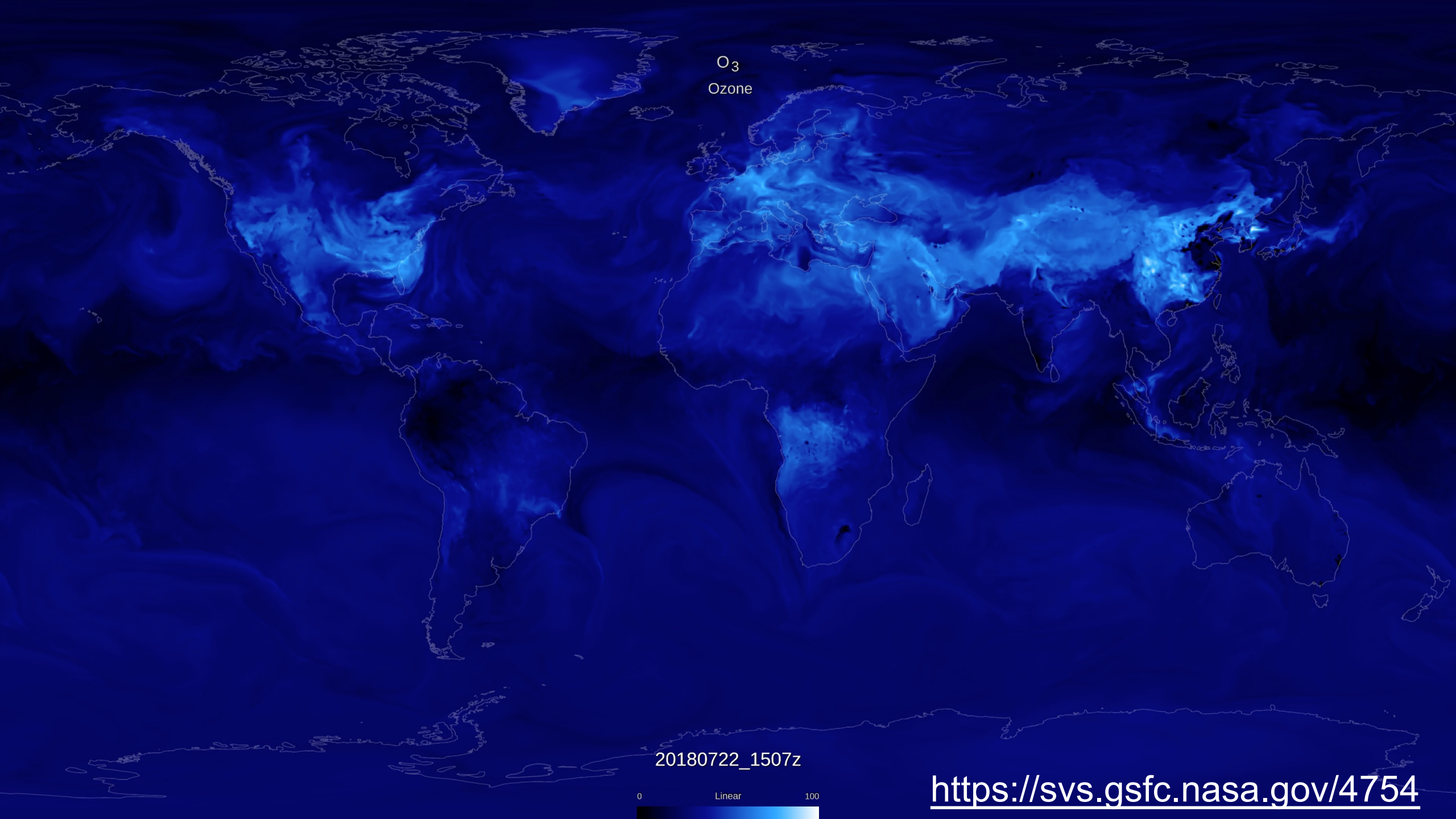




Summary of major GMAO products

System	Focus	Customers/Applications
GEOS-FP “weather prediction”	Impacts of NASA observations on NWP: forefront resolution and complexity	NASA Field Missions (weather, aerosols) Multiple Agencies: NOAA/FAA; NOAA field stations; NRL
GEOS-CF “air quality”	Pioneering global system for atmospheric composition using multiple NASA assets	Health/Air Quality studies (via NASA Applied Sciences) Multiple agencies: NIH, US Army Public Health Center, NOAA
GEOS-S2S “seasonal prediction”	Ensembles of coupled Earth System predictions, emphasizing NASA observations	National ensembles (NMME, SubX), drought/sea-ice prediction Multiple Agencies and international linkages
MERRA-2 “reanalysis”	Stable product for climate studies, emphasizing NASA data	Only current national reanalysis: USGCRP/NCA applications Interagency use: DoE, DoT, NOAA, ...
GEOS-FPIT “mission support”	Stable, well validated, low-latency product for use by NASA instrument teams	More than 20 NASA Instrument Teams
GEOS-Nature Run “mission planning”	Complex Earth System simulations at fine resolution with obs. simulators	Planning for new space-based missions NOAA and broad community; DoE/Smithsonian; NSF

GMAO’s current products that are documented both technically and through robust file specifications, well validated, and released to the broad community for research and applications



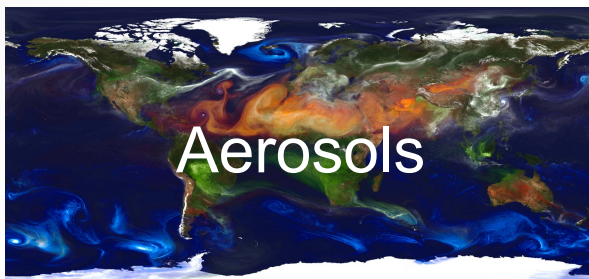
O₃
Ozone

20180722_1507z

<https://svs.gsfc.nasa.gov/4754>

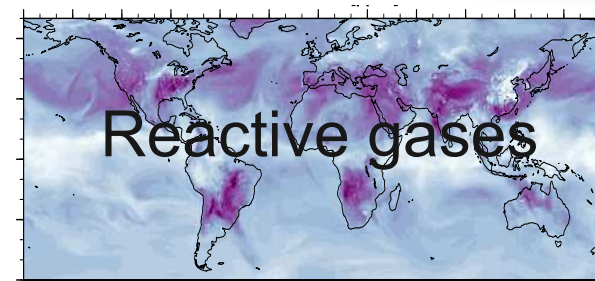
0 Linear 100

Aerosol and Gas Phase Chemistry



- Particulate matter:
 - Carbon
 - Sea salt
 - Dust
 - Sulfate
 - Nitrates
 - (Secondary Organics)

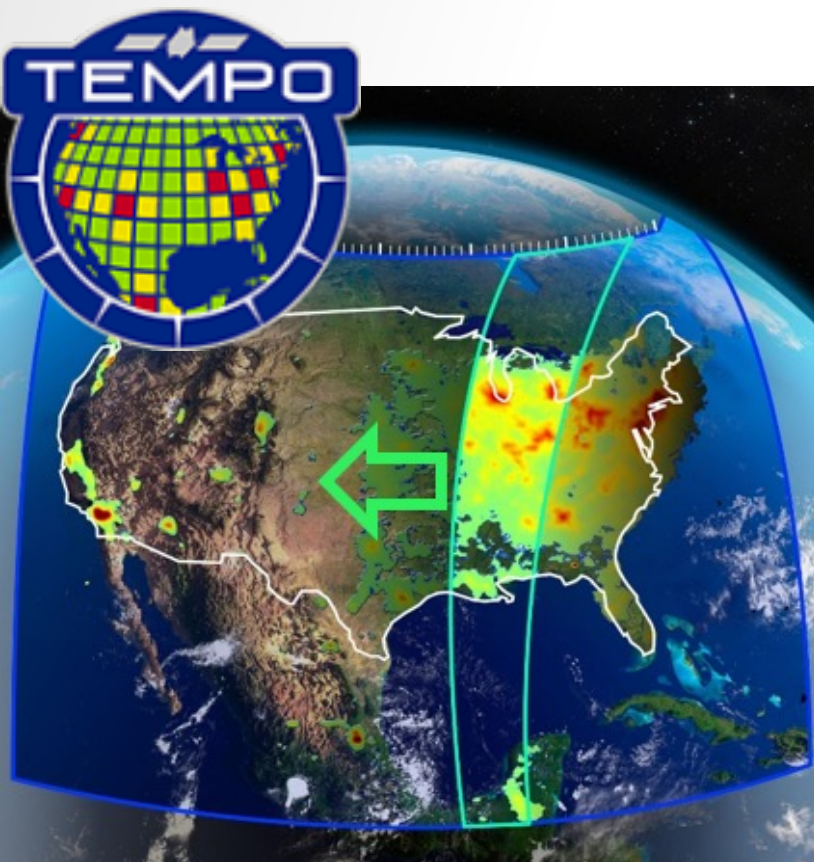
GOCART



- Ozone (O_3)
- Nitrogen dioxide (NO_2)
- Carbon monoxide (CO)
- Volatile organic compounds (VOCs):
 - Formaldehyde
 - Benzene / Toluene
 - And many more!

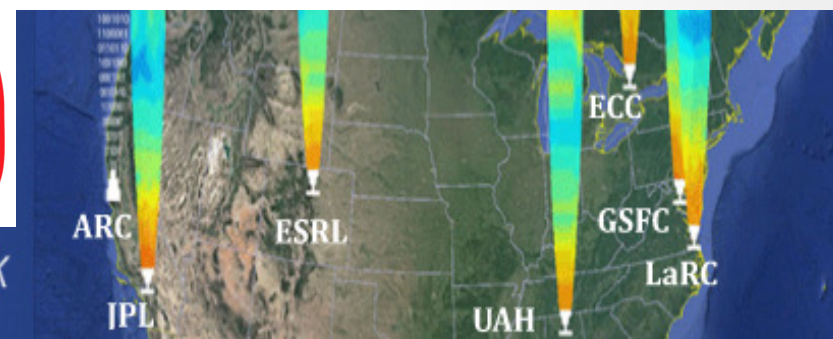
GEOS-Chem

Daily *atmospheric composition* forecast



A realistic stratosphere in GEOS-CF is essential to support a broad range of NASA applications, including:

- Satellite retrievals of trace gases
- Airborne campaigns
- Stratosphere-troposphere exchange



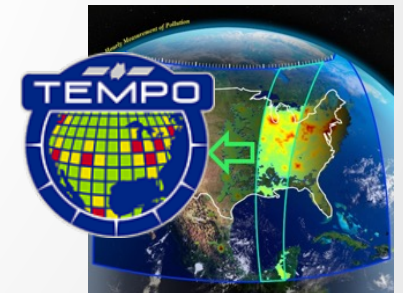
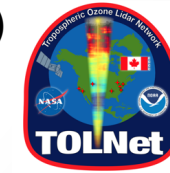
GEOS-CF v1 Status

- Daily GEOS-CF global 5-day composition forecasts at 0.25° (25km) resolution are generated in near-real time:
 - High-resolution historical estimates for fields are available since January 2018
 - Forecast visualizations and links to data available at fluid.nccs.nasa.gov/cf and [/cf_map](#)

Keller, C. A., et al. (2021). **Description of the NASA GEOS composition forecast modeling system GEOS-CF v1.0.** *Journal of Advances in Modeling Earth Systems*, 13, e2020MS002413. <https://doi.org/10.1029/2020MS002413>

Knowland, K. E., et al. (2022). **NASA GEOS Composition Forecast Modeling System GEOS-CF v1.0: Stratospheric Composition.** *JAMES* <https://doi.org/10.1029/2021MS002852>

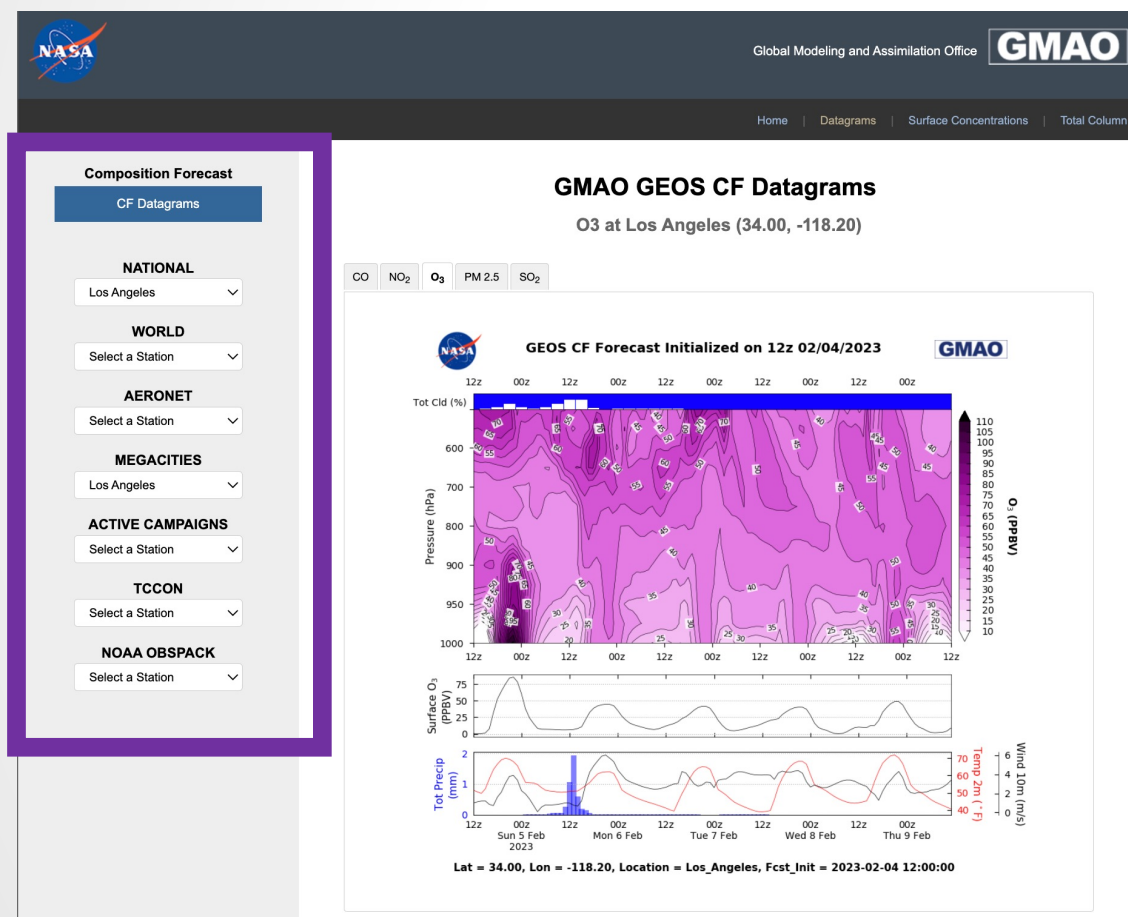
- Applications include:
 - NASA field missions (e.g., SCOAPE, FIREX-AQ, ACT-America, TRACER-AQ)
 - Daily alerts sent to NASA TOLNet lidar teams (Matt Johnson, NASA Ames)
 - TEMPO a priori for trace gas retrieval
 - Cloud platforms, e.g., Google Earth Engine, WRI Resource Watch, CDC Tracker



GEOS-CF output is available online in near real-time

Fluid is a mobile-friendly website

<https://fluid.nccs.nasa.gov/cf/>



<https://portal.nccs.nasa.gov/datashare/gmao/geos-cf/v1/>

<https://opendap.nccs.nasa.gov/dods/gmao/geos-cf/>

GrADS Data Server - info for /gmao/geos-cf/assim/chm_tavg_1hr_g1440x721_v1 : [dds](#) [das](#)

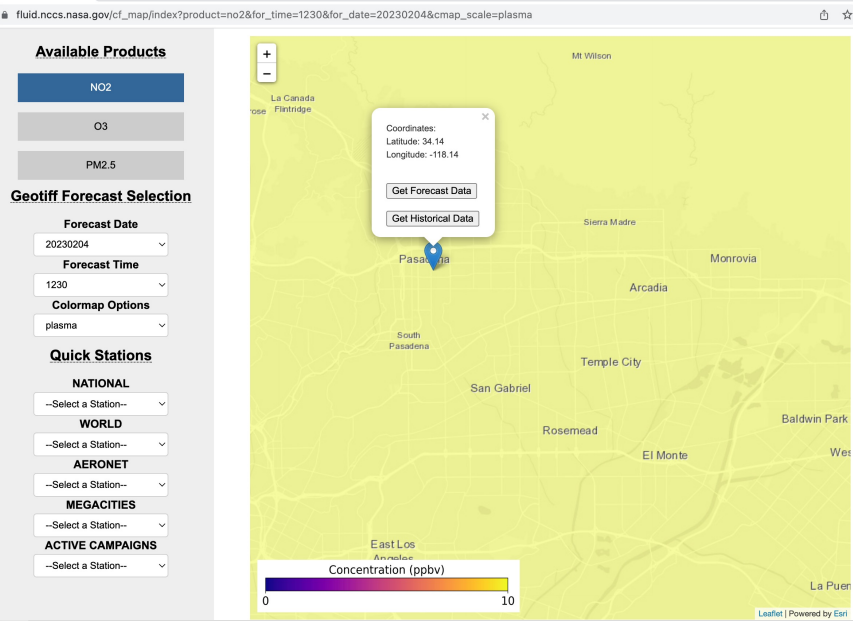
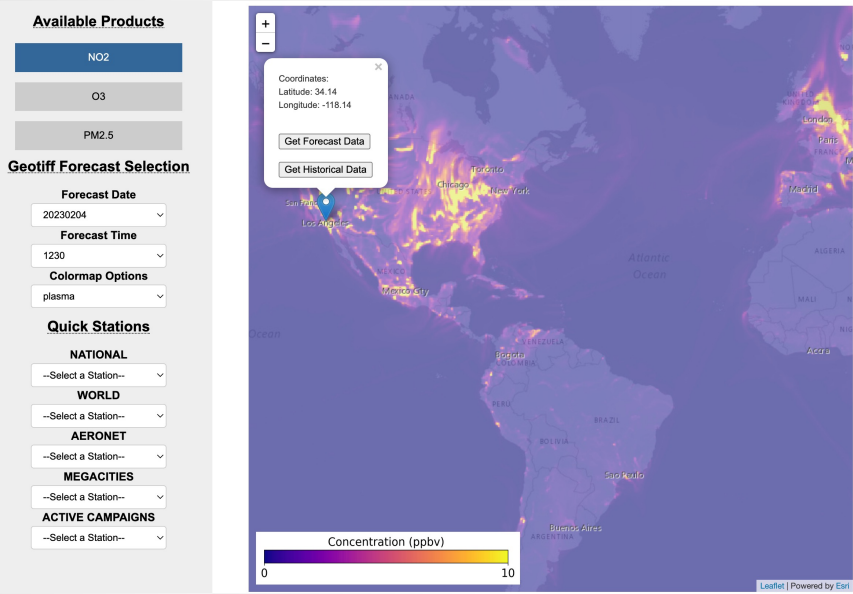
OPeNDAP/DODS Data URL: https://opendap.nccs.nasa.gov/dods/gmao/geos-cf/assim/chm_tavg_1hr_g1440x721_v1

Description: GEOS CF (Composition Forecast)
Documentation: (none provided)
Longitude: -180.0000000000°E to 179.7500000000°E (1440 points, avg. res. 0.25°)
Latitude: -90.0000000000°N to 90.0000000000°N (721 points, avg. res. 0.25°)
Altitude: 72.0000000000 to 72.0000000000 (1 points)
Time: 00:30Z01JAN2018 to 11:30Z31OCT2019 (16044 points, avg. res. 0.042 days)
Variables: (total of 52)
xyle xylene (c8h10, mw = 106.16 g mol-1) volume mixing ratio dry air
dst2 dust aerosol, reff = 1.4 microns (mw = 29.00 g mol-1) volume mixing ratio dry air
hno4 peroxyntic acid (hno4, mw = 79.00 g mol-1) volume mixing ratio dry air
pm25su_rh35_gcc sulfate_particulate_matter_with_diameter_below_2.5_um_rh_35

GEOS-CF forecast imagery is available on-demand



https://fluid.nccs.nasa.gov/cf_map/



Downloadable Data

Chemistry Data

☐ NO₂ ☐ O₃ ☐ PM2.5

--Select File Format--

--Select Dataset--

Download Chem Data

Meteorology Data

--Select File Format--

Download Met Data

Other Data Sets

Pressure Level Plot

Historical CF Plot

NO₂

O₃

PM 2.5

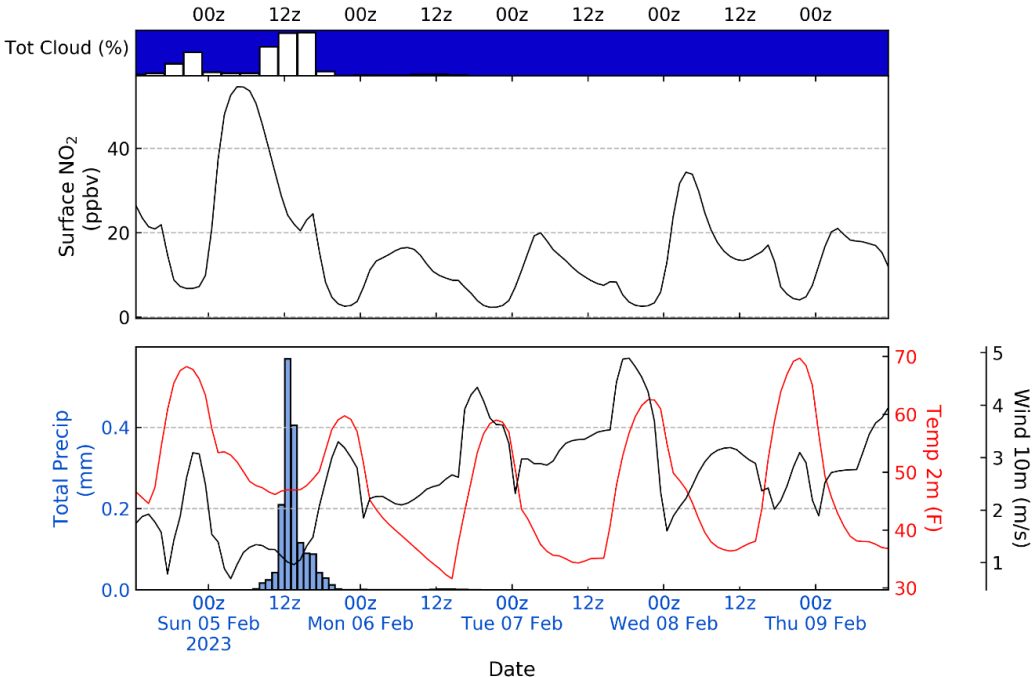
GMAO GEOS CF Datagrams

NO₂ at (34.25N, -118.25E)

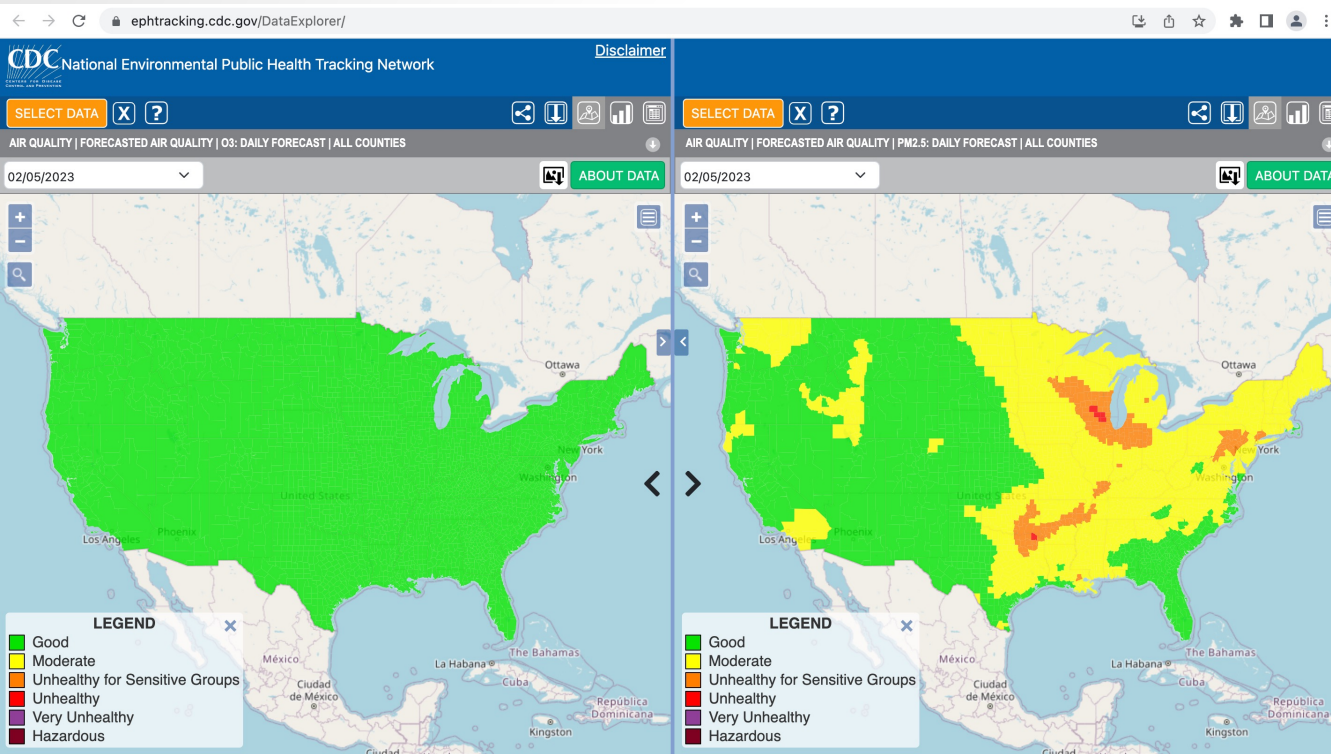


GMAO

GEOS CF Forecast at 34.25N, -118.25E, Initialized on 12z 02/04/2023

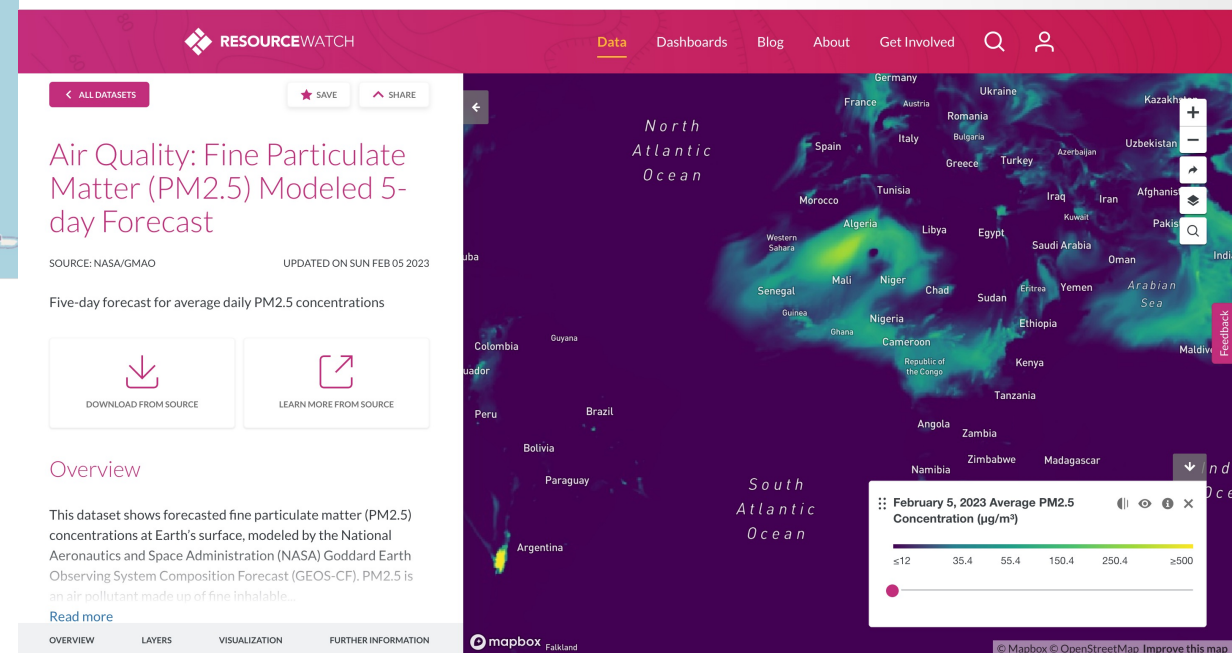


Examples of other ways to access GEOS-CF forecasts



<https://ephtracking.cdc.gov/DataExplorer/>

<https://resourcewatch.org/data/explore>

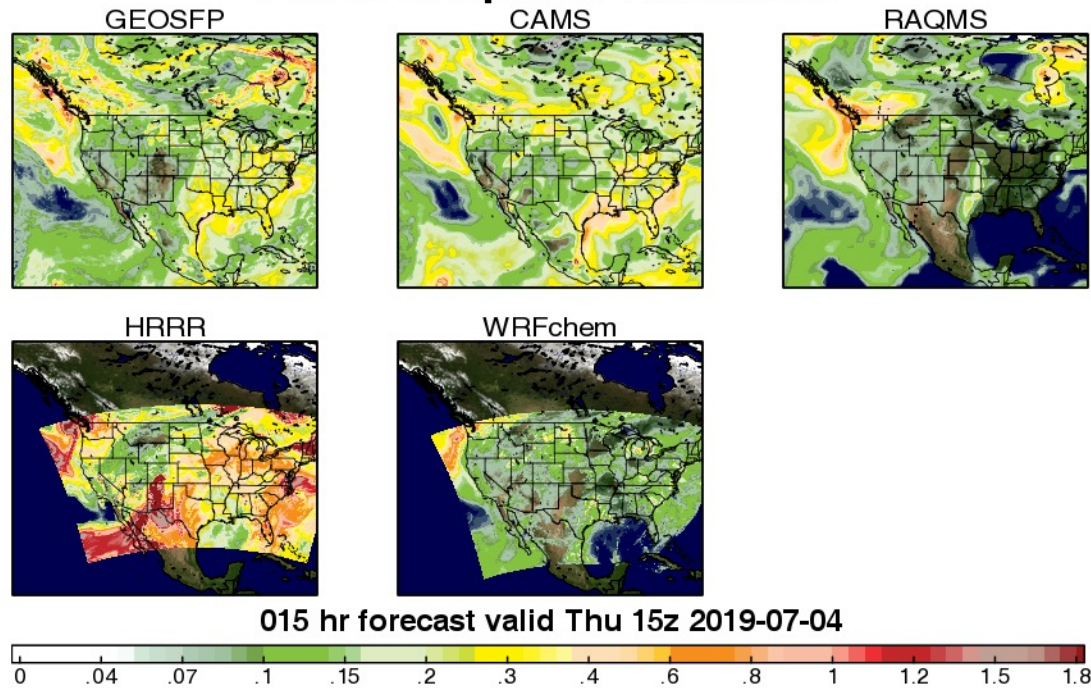


GMAO Field Campaign Support



Forecast Initialized on 00z 07/04/2019

Aerosol Optical Thickness



Global Modeling and Assimilation Office

GMAO<https://fluid.nccs.nasa.gov/missions/>

Mission Support | CF | Reanalysis | Carbon

Navigation

- » FLUID Overview
- » Contact

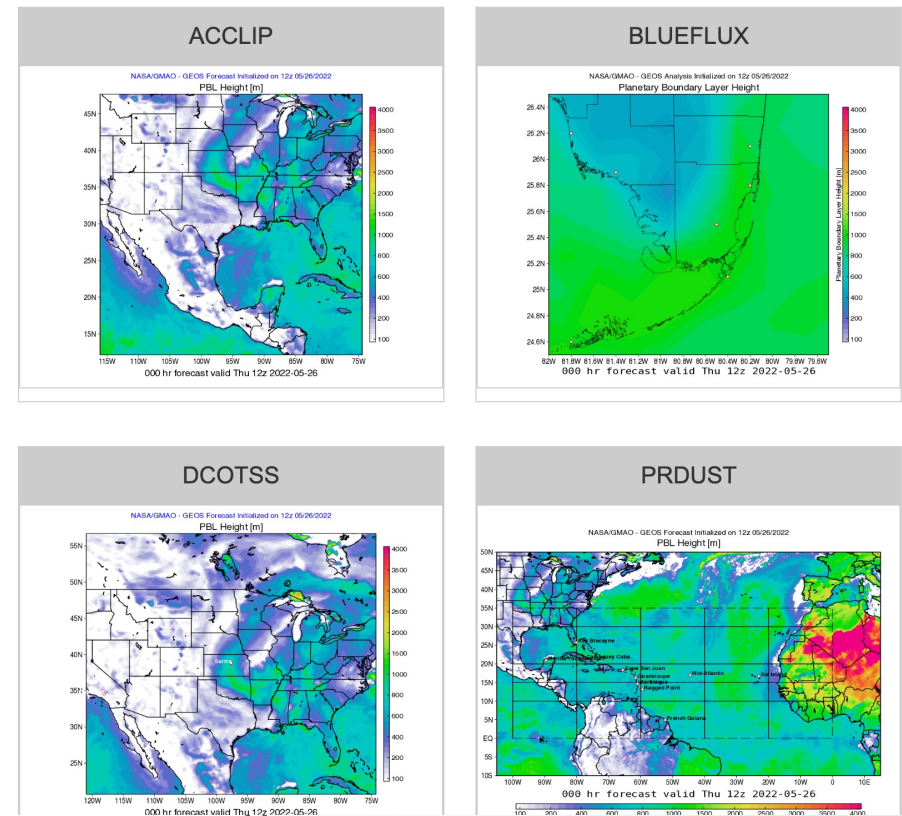
Active Missions

- » ACCLIP
- » BLUEFLUX
- » DCOTSS
- » PRDUST

Non-Active Missions

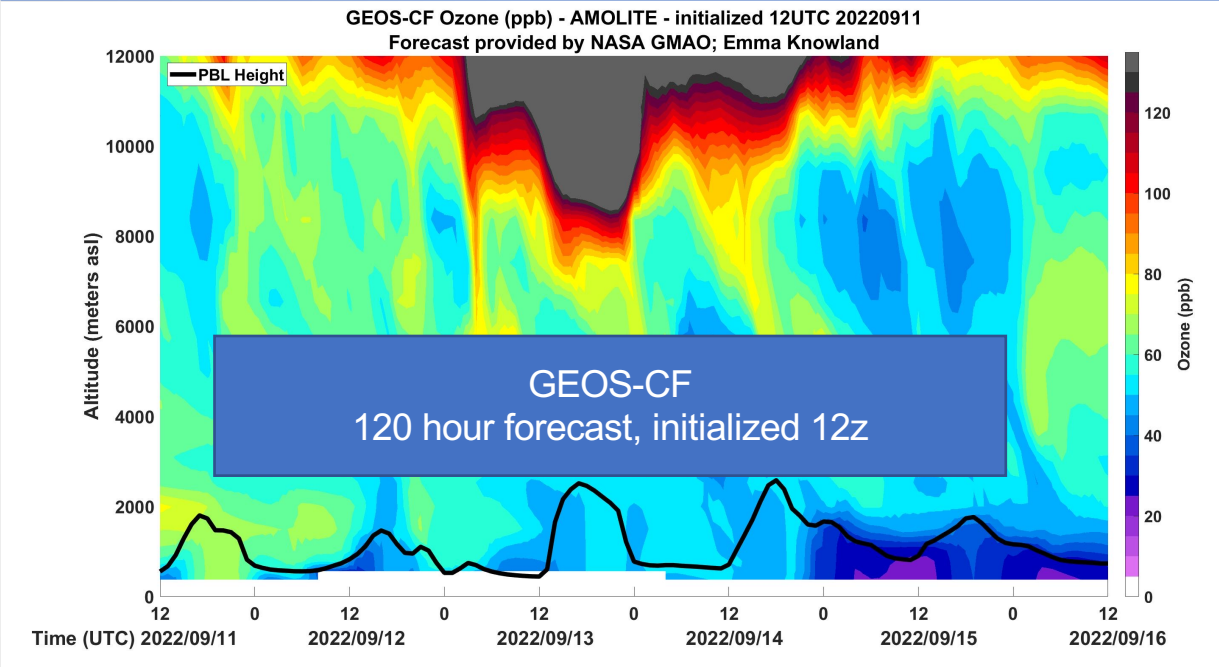
- » ABOVE
- » ACE-ENA
- » AEOLUS-CALVAL
- » ATOM
- » CAMP2EX
- » EPOCH
- » MOSAIC
- » ORACLES
- » SCOAPE
- » SOCRATES
- » TRACER-AQ

GMAO Active Mission Support

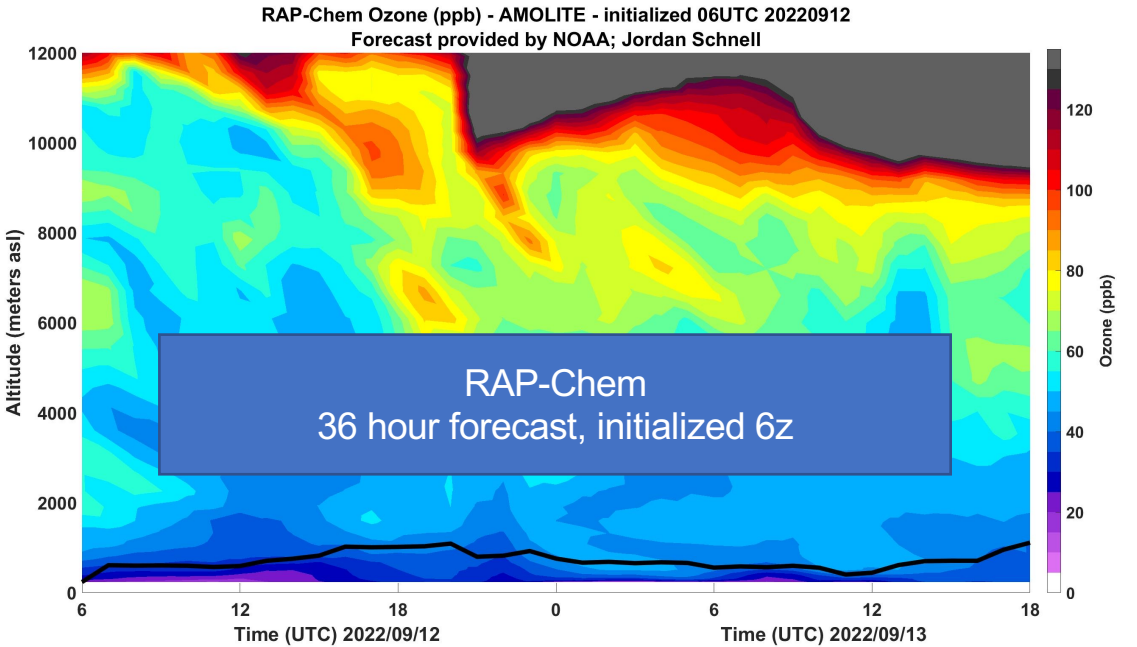
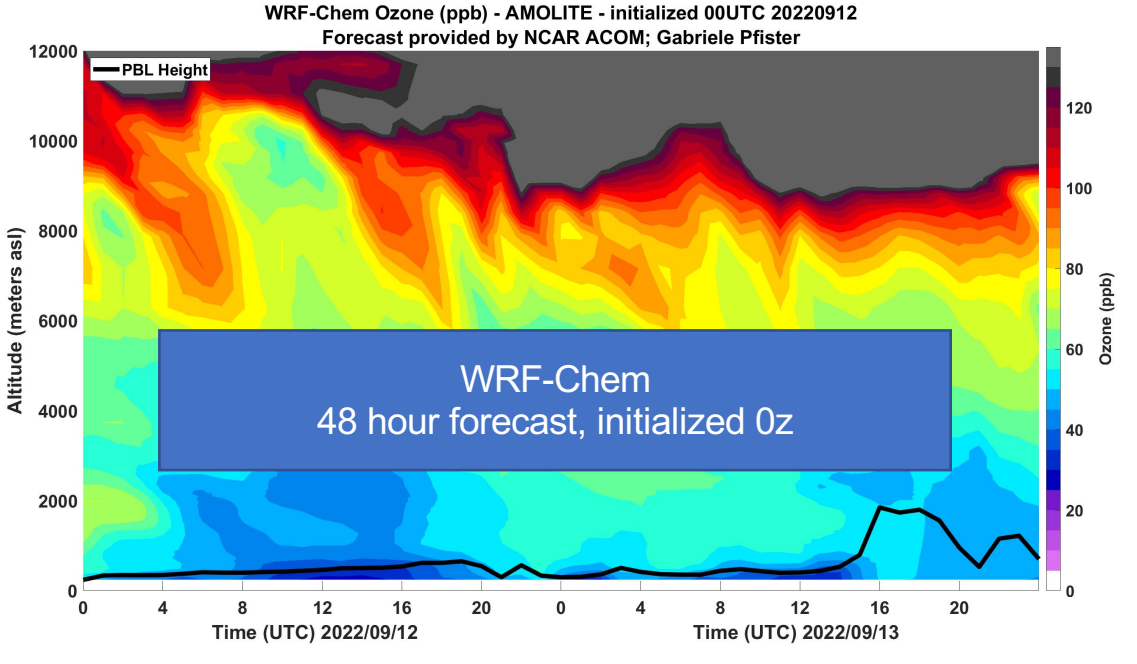
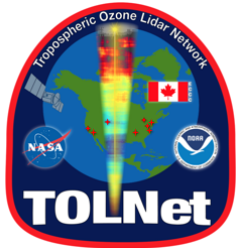


Daily alerts to TOLNet Lidar teams sent by Matt Johnson, NASA Ames

GEOS - CF

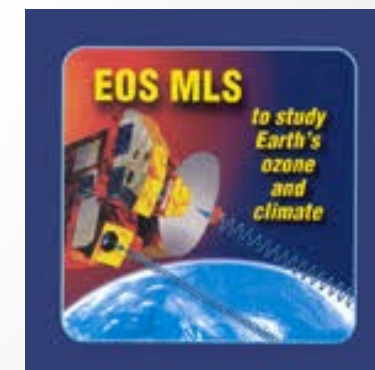
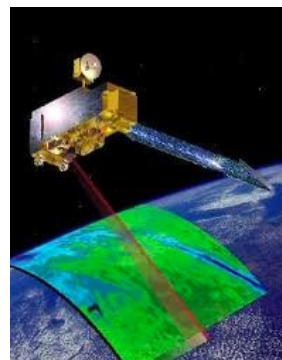
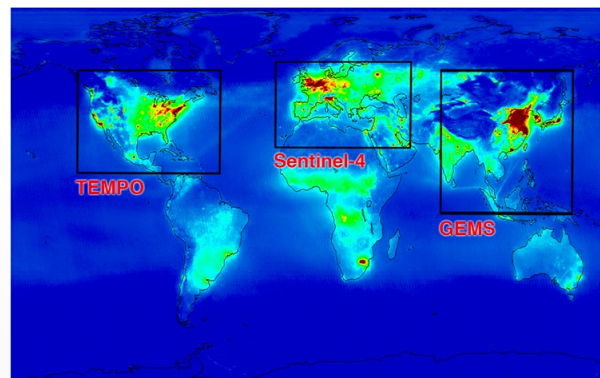
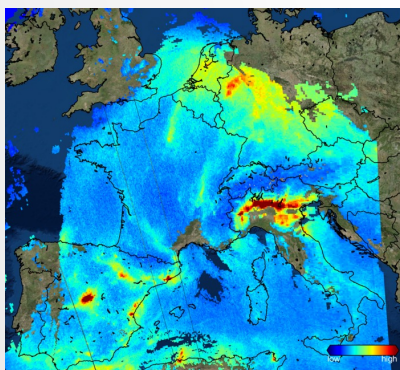


Tailored email alert system using three forecast models provides operators with confidence/uncertainty in predicted features



Planned upgrades for GEOS-CF version 2

- GEOS AGCM update
- Model update to GEOS-Chem v14
 - Improvements to ozone deposition
 - Updates to NO_3 washout → likely reduce $\text{PM}_{2.5}$ bias
- CEDS emission inventory (latest release through 2019)
- Constituent Data Assimilation System (CoDAS)
 - Multi-constituent assimilation with O_3 , NO_2 , SO_2



Mauna Loa's smoking gun

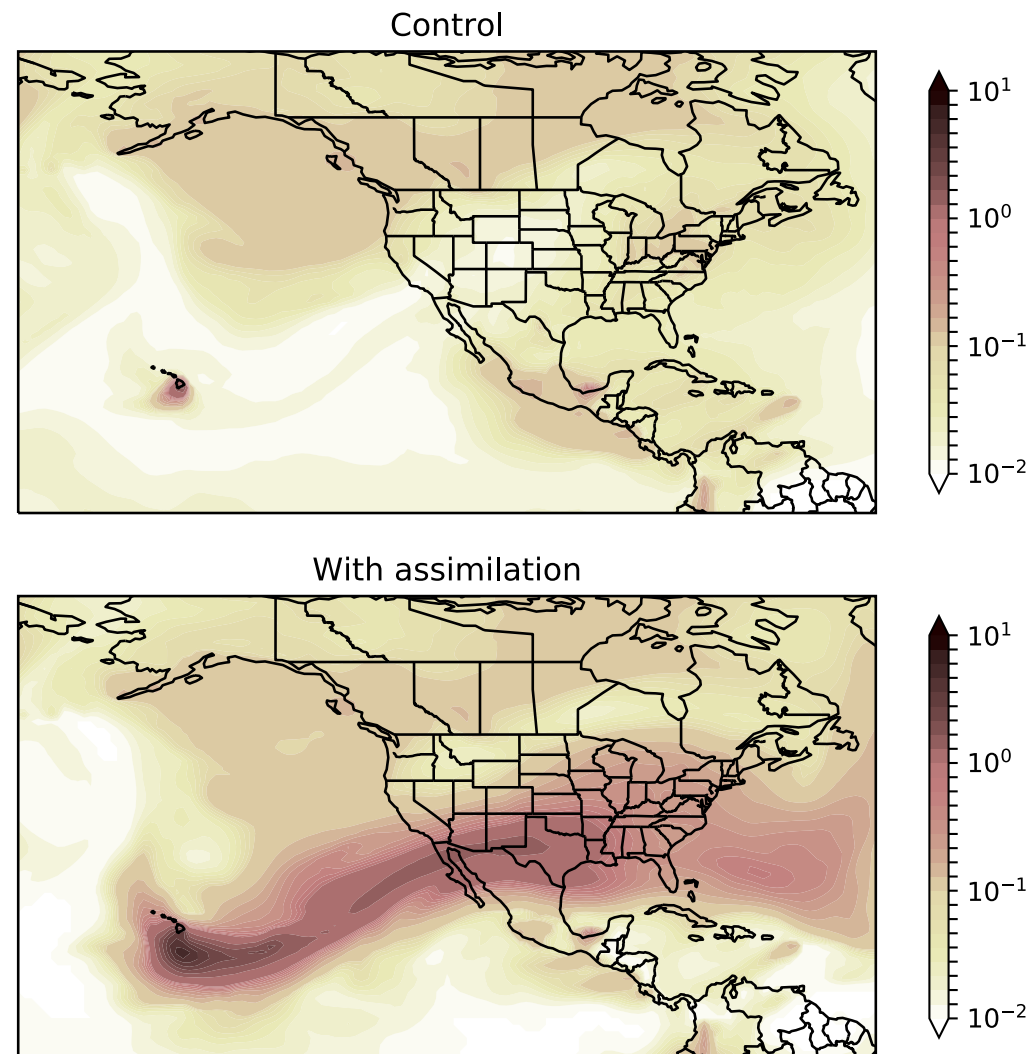
Hawaii's Mauna Loa began erupting on Nov. 27, 2022.

The resulting volcanic plume of sulfur dioxide (SO_2) can be seen from space with satellite instruments such as NASA's Ozone Monitoring Instrument (OMI).

Without assimilation (control run), the model solely relies on historical estimates of persistent degassing, missing the large release of SO_2 from Mauna Loa's eruption.

GEOS CoDAS experiment assimilating OMI SO_2 realistically captures active volcanic plumes.

Sulfur dioxide total column [DU], 2022-12-02



Model simulated daily average total column of SO_2 for Dec. 2, 2022 without (top) and with (bottom) assimilation of OMI SO_2 .

Global -> local scale estimates



Google Earth

Sep 16, 2022 · 3 min read · [Listen](#)

How NASA and Google are teaming up to understand and analyze air quality around the world

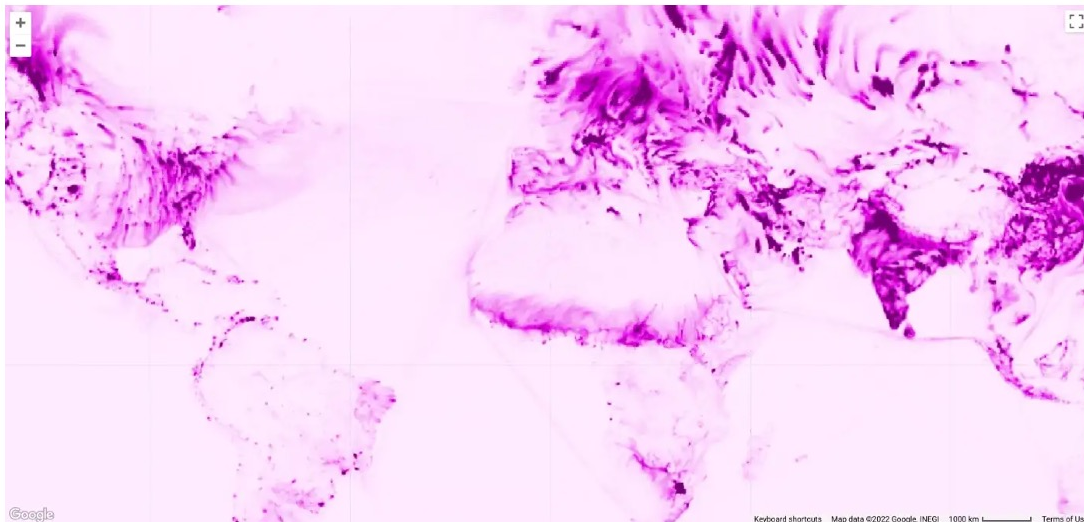
By Karin Tuxen-Bettman, PhD, Program Manager, Google Earth Outreach

Nicholas Clinton, PhD, Developer Advocate, Google Earth Engine

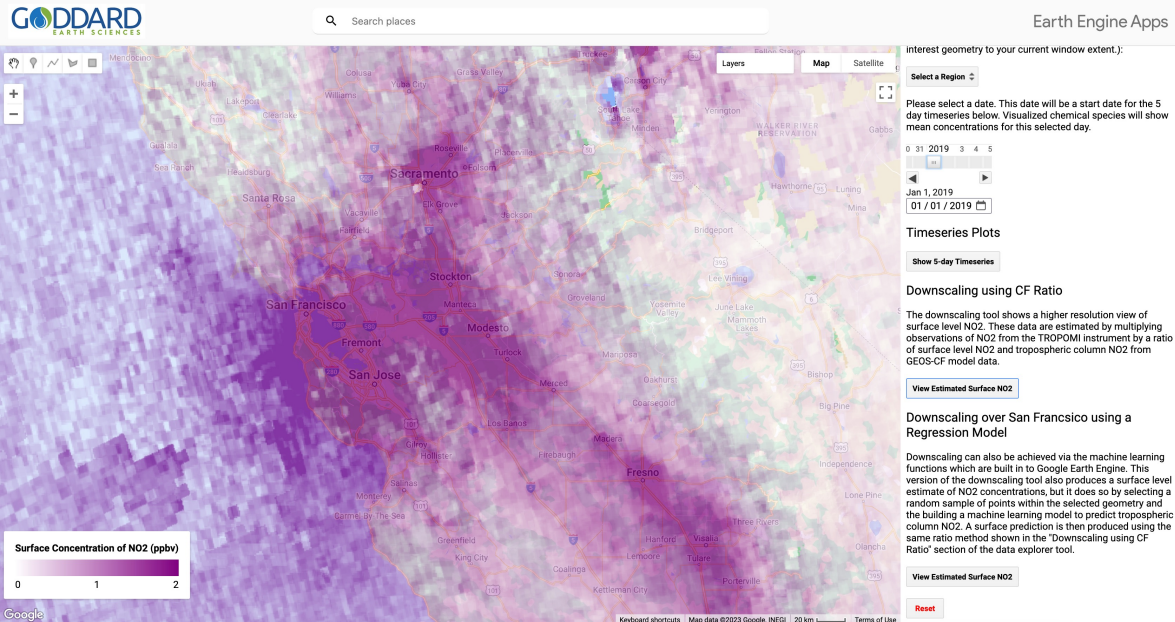
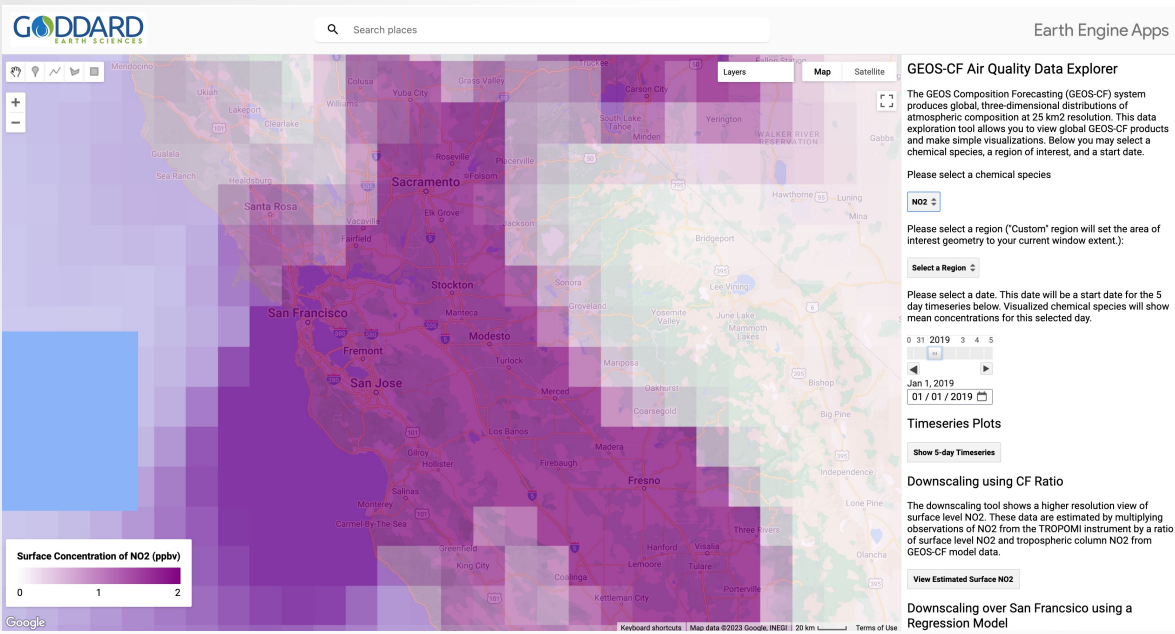
Argyro Kavvada, PhD, Program Lead, Sustainable Development Goals, Applied Sciences Program, NASA Earth Science Division

Part of the NASA-Google Partnership, select GMAO products are now being ingested into GEE:

- **GEOS-CF** hourly-average surface fields (chemistry and meteorology)
- **MERRA-2** hourly-average aerosol fields



Global -> local scale estimates



- Part of the NASA-Google Partnership, select GMAO products are now being ingested into GEE:
- **GEOS-CF** hourly-average surface fields (chemistry and meteorology)
 - **MERRA-2** hourly-average aerosol fields

Google Earth Engine and Google Cloud tools provide researchers the option to layer together different datasets in GEE and perform statistical methods and machine learning techniques which can downscale the global model reanalysis and forecasts to help improve on the biases at the sub-grid scale.

GMAO's Products



	What it is	Changes
MERRA-2	Atmospheric reanalysis + aerosols & ozone	Will run through 2025
MERRA-2 Ocean	Ocean reanalysis (1982-2025)	To be released in 2023
GEOS-S2S (SubX-to-Seasonal Prediction)	Nine-month coupled prediction	V3 will replace V2 in 2023 V4 will come with MERRA-3 (circa 2025)
GEOS-FP (Forward Processing)	Real-time NWP, with an Earth system flavor	GEOS-6 in early FY2023 Includes the transition to JEDI
GEOS-IT (Instrument Teams)	Real-time meteorological analysis to support >30 NASA Instrument Teams	GEOS-IT will replace GEOS-FPIT ... first data (2018) released
GEOS-CF (Composition Forecasting)	Analysis and forecasts of air quality, etc., using complex chemistry	Major new release planned for mid 2023
SMAP L4	Root zone soil moisture and carbon fluxes	Annual updates for new SMAP versions
GEOS-R21C (Reanalysis of the 21 st Century)	Special analysis focused on novel observations in EOS/post-EOS era	Testing in late stages; will commence in spring 2023
MERRA-3	Earth system reanalysis, based on JEDI coupled data assimilation	Model and DA are being built; includes JEDI-based coupled assimilation

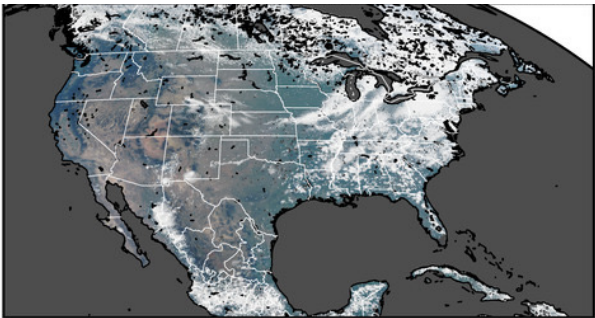
Moving into the Next Decade

GEOS is a mature Earth System model and data assimilation system

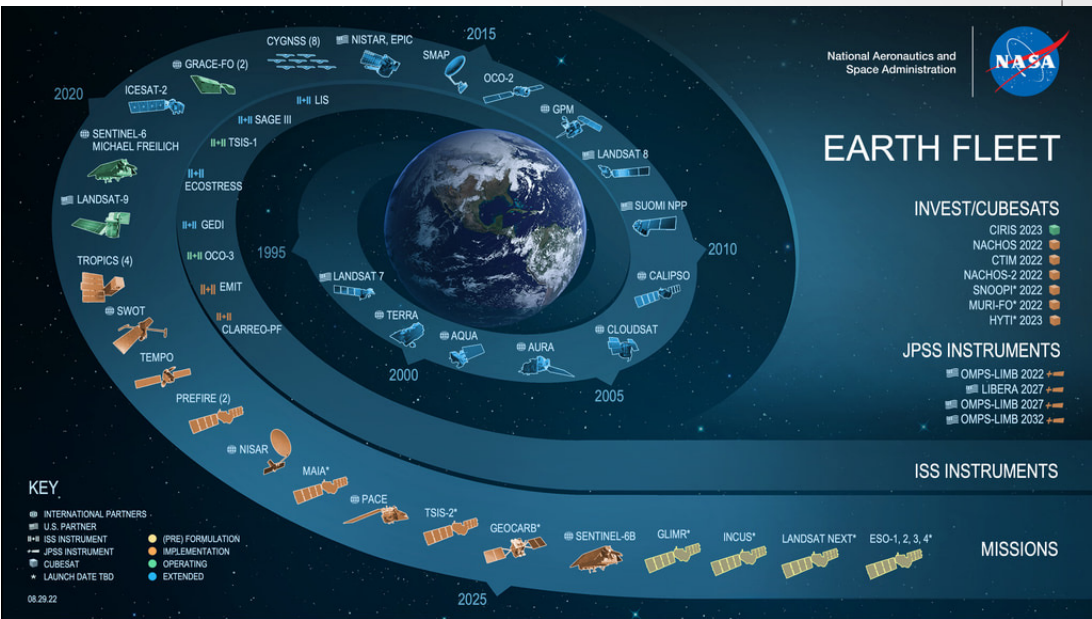
As such it provides a robust platform for assimilation of emerging atmospheric composition satellite measurements on a global scale, and a foundation for downscaling and detailed regional modeling.

GEOS has a mature OSSE infrastructure has been applied to meteorological and atmospheric composition applications alike and can be instrumental for defining the AC observing system of the future.

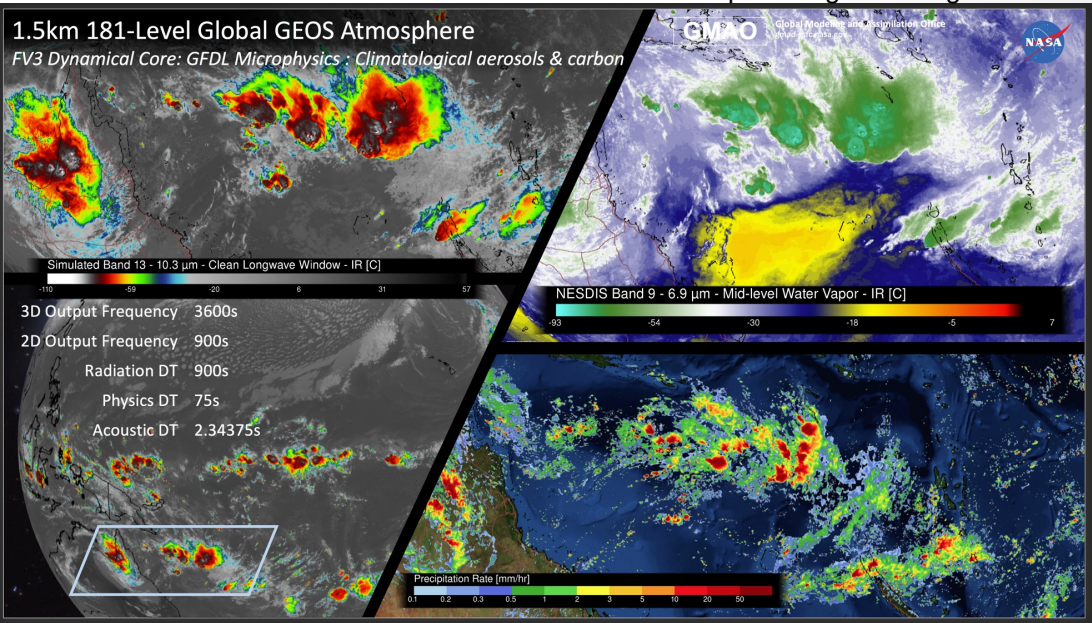
Simulated TEMPO RGB image



Castellanos et al., 2019 Atmosphere

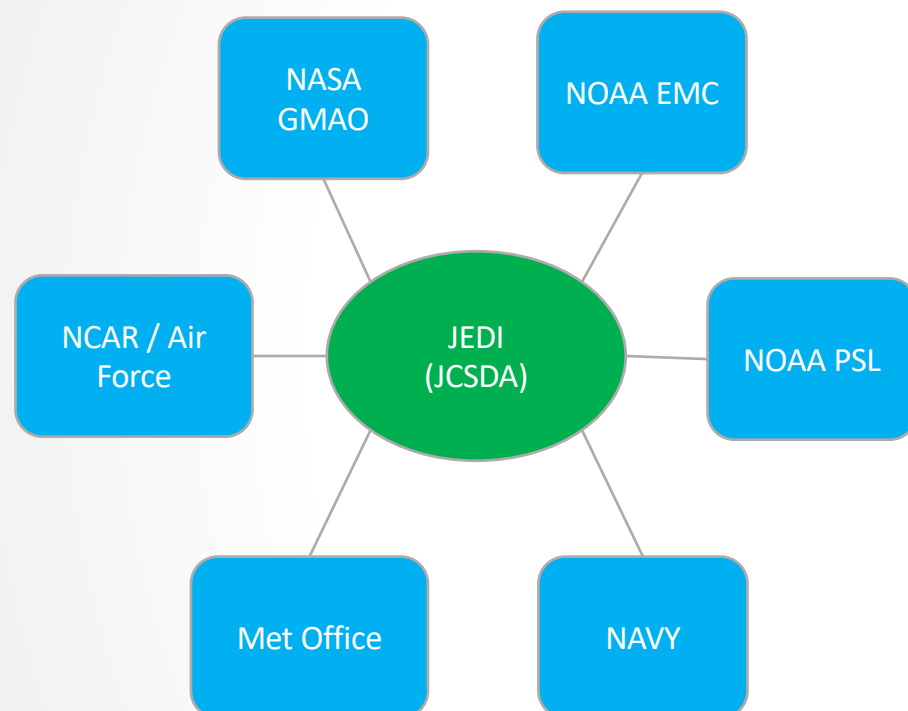


<https://svs.gsfc.nasa.gov/30065>



https://gmao.gsfc.nasa.gov/global_mesoscale/diamond_phasel

Community benefit of JEDI data assimilation software



JEDI, managed by the Joint Center for Satellite Data Assimilation (JCSDA), is truly a community effort with no one agency dictating the development.

The only difference between the way GMAO uses JEDI and the way another center uses it is the configuration file.

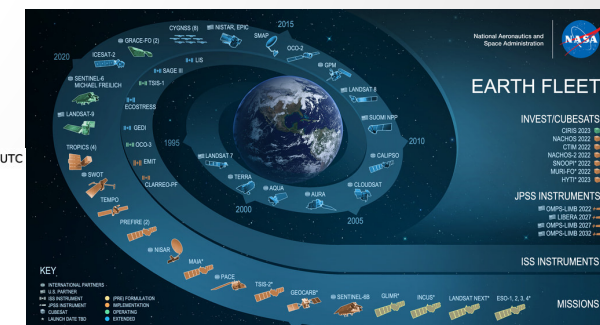
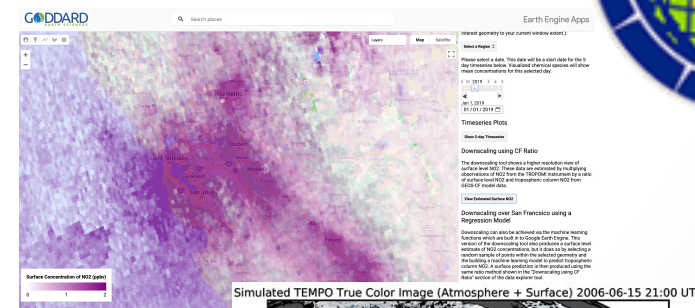
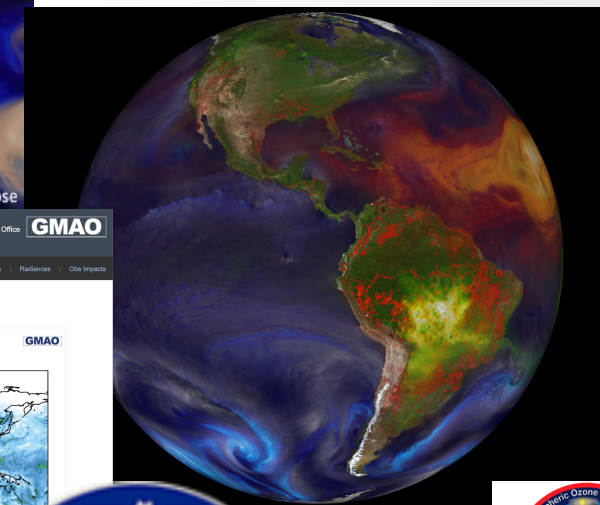
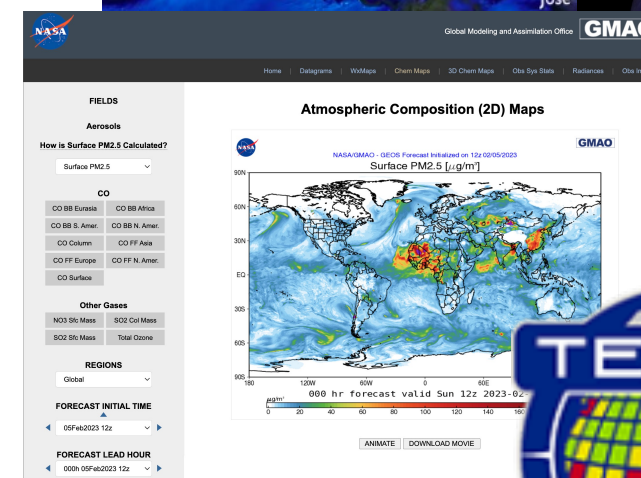
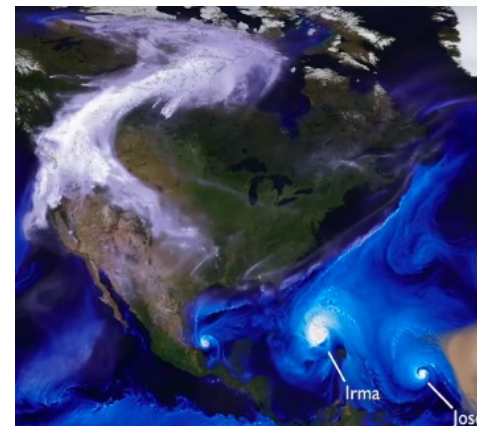
It can be thought of as a repository exhibiting the state-of-the-art in data assimilation knowledge made available to everybody.

As new NASA data come online they can be made available to many users in very short order.

Summary

- ❖ GMAO has a state-of-the-science Earth System model and data assimilation system
- ❖ Involved and invested in new data assimilation infrastructure for coupled Atmosphere-Ocean data assimilation system
- ❖ GMAO supports NASA missions and campaigns with modeling support from sophisticated OSSEs to on-demand forecast imagery on FLUID
- ❖ GMAO products are available to the public with file formats for both scientists and air quality managers to use.
- ❖ NASA products are research products

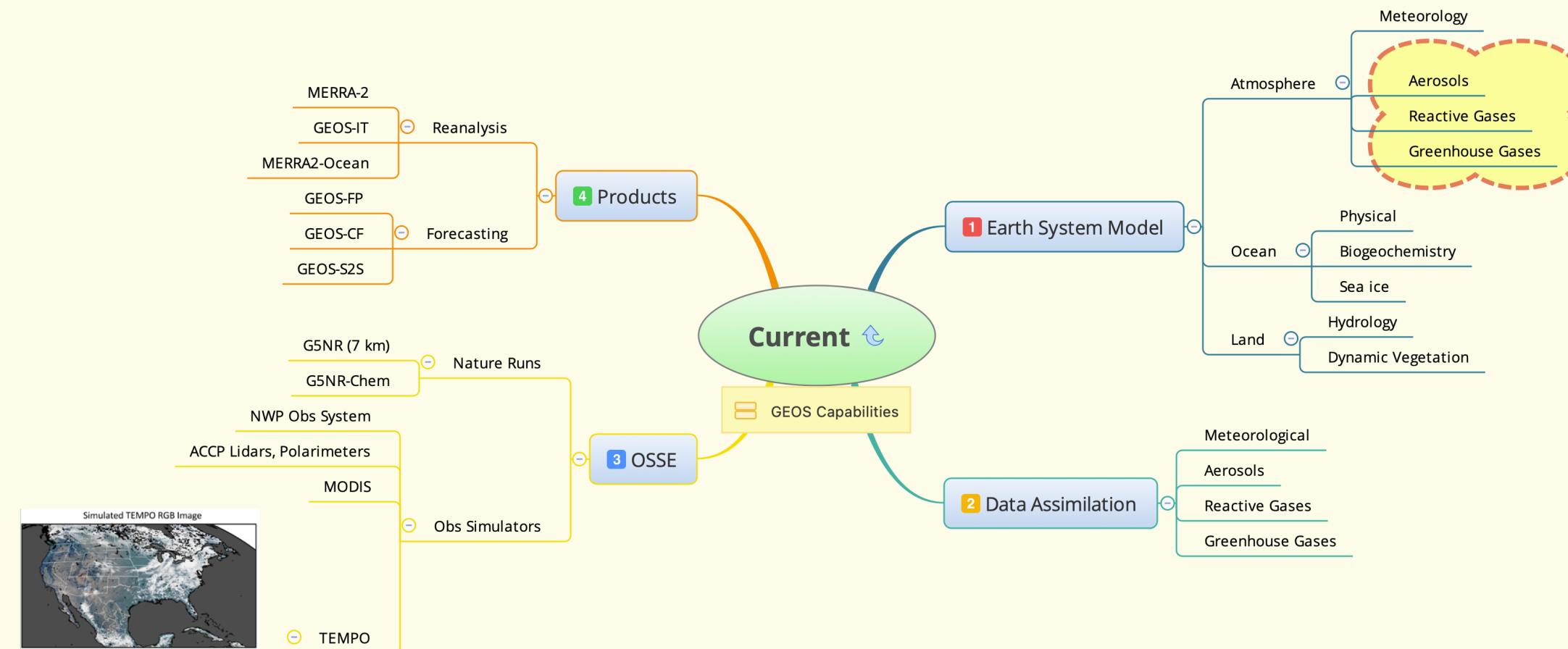
Thank you for listening!





Extra slides

Current GEOS Capabilities



Emerging GEOS Capabilities

